

Quantum nonlocality or nonergodicity?

A critical study of Bell's arguments

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Abstract

We pay attention that through Bell's arguments one can not distinguish quantum nonlocality and nonergodicity. Therefore experimental violations of Bell's inequality can be as well interpreted as supporting the hypothesis that stochastic processes induced by quantum measurements could be nonergodic.

1 Introduction

We recall that the hypothesis of ergodicity of quantum mechanics was discussed in a number of papers [1]-[5]. There was even performed one (!!!) experiment for testing the hypothesis of ergodicity for quantum measurements – in neutron interferometry [2]. The result of this experiment can be interpreted as a sign in favor of the hypothesis that quantum mechanics is ergodic. Unfortunately, this experimental activity was not continued, in spite of new proposals [3] (see also [4], [5]).

In this note we question again the ergodicity of quantum mechanics in connection with Bell's arguments in favor of quantum nonlocality [6]. Our conclusion is that experimental violations [7] of Bell's inequality can be as well interpreted as supporting the hypothesis that stochastic processes induced by quantum measurements could be nonergodic.

2 Ergodicity: coincidence of time and ensemble averages

We recall that a stationary stochastic process $x(t, \omega)$ (here ω is a chance parameter) is (linearly) *ergodic* if

$$Ex \equiv \int_{\Omega} x(t, \omega) d\rho(\omega) = E_{\text{time}}x \equiv \lim_{n \rightarrow \infty} \frac{x(t_1, \omega) + \dots + x(t_n, \omega)}{n}. \quad (1)$$

Here ρ is a probability measure (so a process is ergodic with respect to some probability measure). So the law of large numbers holds true. Here the ensemble average $Ex = \int_{\Omega} x(t, \omega) d\rho(\omega)$ (it does not depend on t , since the process is stationary) can be approximated with an arbitrary precision by the time-average with respect to almost any realization ω .

3 Quantum ergodicity?

In quantum mechanics we consider the chance parameter ω labeling runs of experiments for measuring some quantum observable x for systems prepared in the state D . Thus for any run ω we obtain a discrete process $x(t_1, \omega), \dots, x(t_n, \omega), \dots$ (results of measurements of x). We pay attention that $x \equiv x^D(t)$, so it depends on D . In quantum formalism it is assumed that x and D are represented by self-adjoint operators, moreover, D is positively defined and it has the unit trace. The quantum average is given by the von Neumann trace formula: $\langle x \rangle_D = \text{Tr } Dx$.

In a huge number of experiments there was demonstrated (long before Bell's proposal) that the quantum average coincides with the time-average:

$$\langle x \rangle_D = E_{\text{time}}x, \quad (2)$$

so

$$\text{Tr } Dx = \lim_{n \rightarrow \infty} \frac{x(t_1, \omega) + \dots + x(t_n, \omega)}{n}.$$

However, besides Summhammer's experiment [2], there were no experimental results confirming quantum ergodicity, namely, coincidence of the time average $E_{\text{time}}x$ (and hence the quantum average) and the ensemble average Ex .

4 Nonlocality and nonergodicity?

There were no doubts that the equality (2) should hold true even for observables considered in the EPR-Bohm experiment. One of main inventions of J. Bell was assuming the ergodicity of quantum mechanics and, hence, the coincidence of ensemble and time averages, see (1). Under such a (hidden) assumption he could identify quantum averages with ensemble averages. The logic of such an identification is the following: we know that quantum averages are well approximated by time averages; but the latter coincide (through ergodicity) with ensemble averages; therefore quantum averages are well approximated by ensemble averages.

In this framework he derived his inequality and came to the conclusion that the quantum formalism is incompatible with local realism. In fact, personally J. Bell this was the conclusion about quantum nonlocality.

We now remark that if the stochastic process induced by measurements of polarizations in pairs of entangled photons is nonergodic, then there is no reason to identify the time and ensemble averages and hence no reason to identify the ensemble and quantum averages.

In the situation when the hypothesis on quantum ergodicity has practically no experimental confirmations, to follow Bell's arguments is really a risky project.

Conclusion. *Experimental tests demonstrating violation of Bell's inequality can be as well interpreted as tests demonstrating violation of ergodicity for quantum measurement process.*

Experimental recommendations. *It would be natural to switch the experimental research in quantum foundations from the study probabilistic behavior of entangled system to experiments that could test the "pure" (so not mixed with nonlocality) ergodicity.*

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